CREWES

Synthetic Seismograms in a 3D Orthorhombic Medium

P.F. Daley

and

G.F. Margrave

UNIVERSITY OF CALGARY

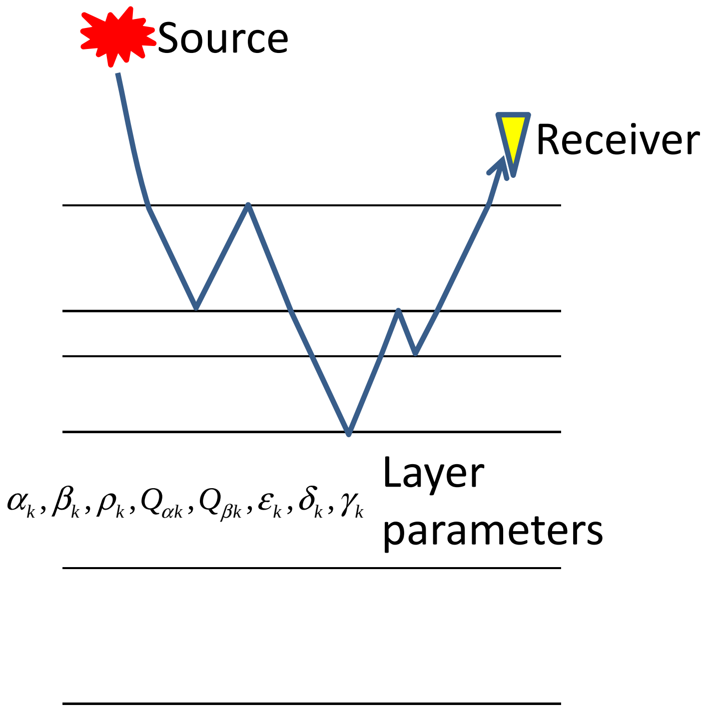
NSERC CRSNG

Outline

- The Reflectivity and Reflectvity_fd methods
- The *reflectivity_fd* toolbox
- The 3D Orthorhombic code
  – Azimuth scanning
  – Examples

Reflectivity method

Fuchs and Muller (1971), Kennett (1983)

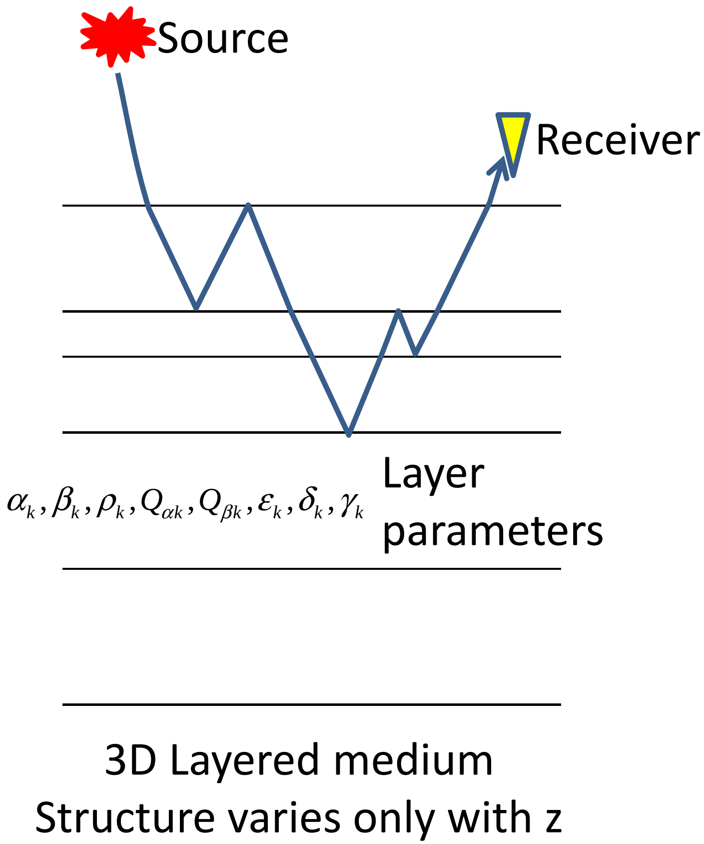


3D Layered medium
Structure varies only with z

- **Calculates a complete 3D body-wave seismogram in the frequency-wavenumber domain.**
- **Includes all multiples and mode conversions.**
- **Has been extended to the anisotropic and visco-elastic cases.**
- **Layer propagation done with *Propagator Matrices* which predict infinitely many multiples and multi-modes.**
- **Integration over lateral wavenumbers by inverse Hankel transform.**
- **Run time is proportional to the number of layers.**

Reflectivity_fd method

Mikhailenko (1970-present), Daley (1975-present)



- **Uses finite-differences in z and t instead of frequency-domain propagator matrices.**
- **Integration over lateral wavenumbers by inverse Hankel transform.**
- **Includes all multiples and mode conversions.**
- **Has been extended to the anisotropic and visco-elastic cases.**
- **Model parameters can vary with depth at the finite-difference grid spacing.**
- **Run time is <u>independent of</u> the number of layers.**

See especially: Daley, P. F., 2010, P-SV wave propagation in a radially symmetric vertically inhomogeneous TI medium: Finite difference hybrid method, CREWES Research Report.

Reflectivity_fd toolbox
Matlab codes

Physics	Offset geometry	VSP geometry	Azimuthal scan geometry
Acoustic with Q	Released	Released	-
Elastic isotropic with Q	Released	Released	-
VTI elastic with Q	Released	Released	-
Orthorhombic elastic with Q	Upon request	Not yet	Upon request

- Matlab codes allow easy debugging and are an excellent research tool. ***Beta release*** now downloadable from www.crewes.org\‘For our sponsors’
- Most codes have been converted to C++ via “Matlab coder”.
- Older Fortran codes also exist.
- C++ and Fortran codes are considerably faster but Matlab works acceptably on a modern computer.

Orthorhombic Reflectivity_fd

- **The 3D orthorhombic problem with lateral homogeneity has been considered for an anisotropic depth dependent structure overlying a halfspace.**
- **The *(x,y)* coordinates are removed with a combination of finite sine and cosine transforms, leaving a FD problem of 3 coupled equations for the 3 components of displacement in depth *(z)* and time *(t)*.**
- **Multiple source types yield (consistent) 9C data sets.**
- **The shooting geometries include:**

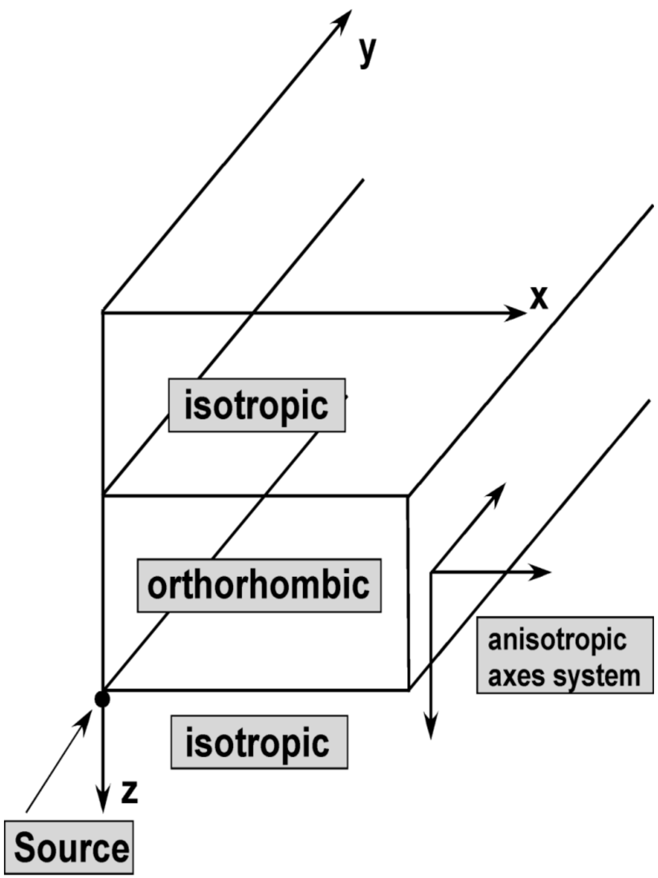
  1. Surface sources with surface receivers along a fixed azimuth.

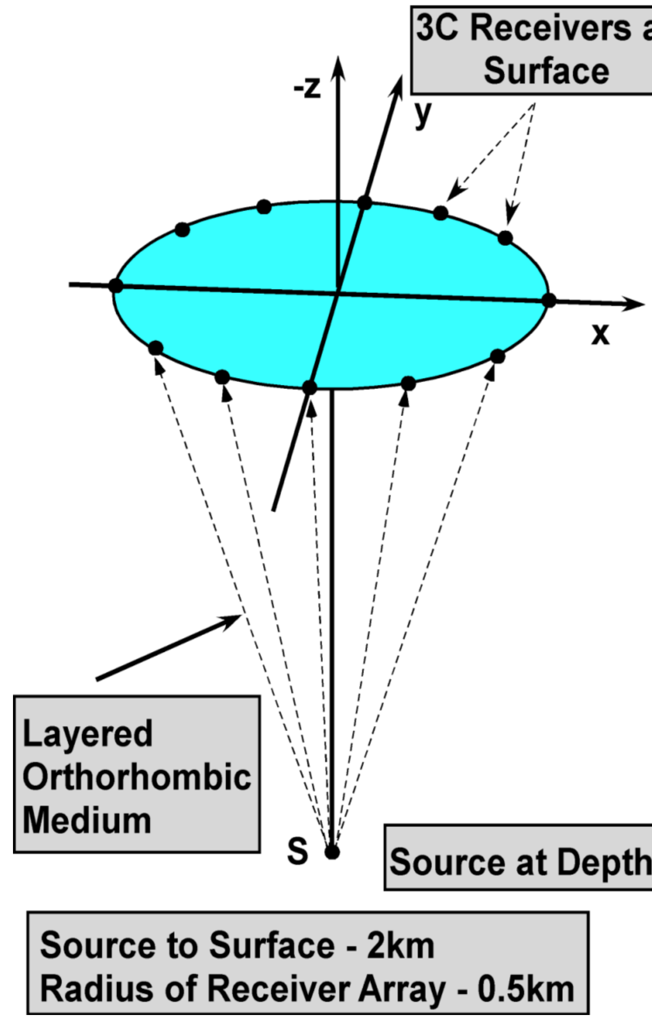
  2. An incremental azimuth shoot over 360 degrees, with a fixed source location and source – receiver offset.
- **Examples of both 1 and 2 will be shown.**

Orthorhombic Reflectivity_fd

- The 2nd shooting pattern, over azimuth, provides an indication of shear-wave splitting, which is a useful modeling application.
- This use is only of consequence if the vertical fractures in an anisotropic medium are aligned perpendicular to the horizontal layering.
- This is highly restrictive and for a more general solution of vertical fracturing in a TI medium the 9 anisotropic parameters associated with an orthorhombic medium are insufficient.
- This leads to adding at least 4 more anisotropic parameters to the initial problem and construct a more general triclinic solution involving 13 anisotropic parameters.
- The mathematics for this extension is significant and it is wondered if solving the problem in its most general form, using all 21 anisotropic parameters, would be the optimal path to follow.

Current model and shooting geometry





Density-normalized elastic constants

Voigt notation

Isotropic Medium (plexiglass)

$$\begin{bmatrix} 7.56 & 3.60 & 3.60 & & & \\ & 7.56 & 3.60 & & & \\ & & 7.56 & & & \\ & & & 1.90 & & \\ & & & & 1.90 & \\ & & & & & 1.90 \end{bmatrix}$$

2 independent values

Density = 1.19 gm/cm^3

Orthorhombic Medium (phenolic)

$$\begin{bmatrix} 8.70 & 4.68 & 5.07 & & & \\ & 13.25 & 5.13 & & & \\ & & 12.25 & & & \\ & & & 2.89 & & \\ & & & & 2.34 & \\ & & & & & 2.28 \end{bmatrix}$$

9 independent values

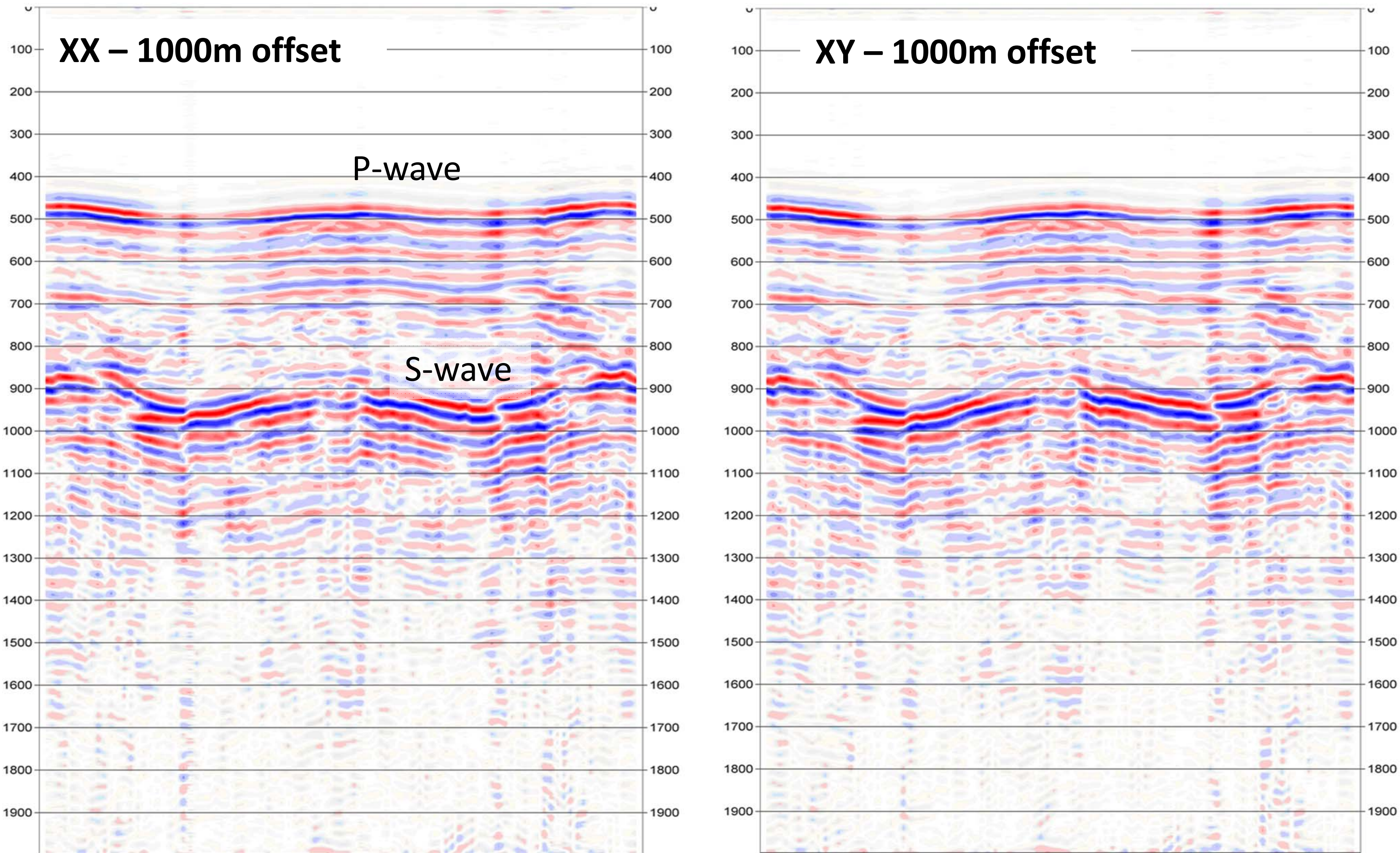
Density = 1.39 gm/cm^3

A_{ij} units – $(km/s)^2$

Values from: Mahmoudian, F, 2013, Physical Modeling and Analysis of Seismic Data from a Simulated Fractured Medium, PhD thesis, University of Calgary

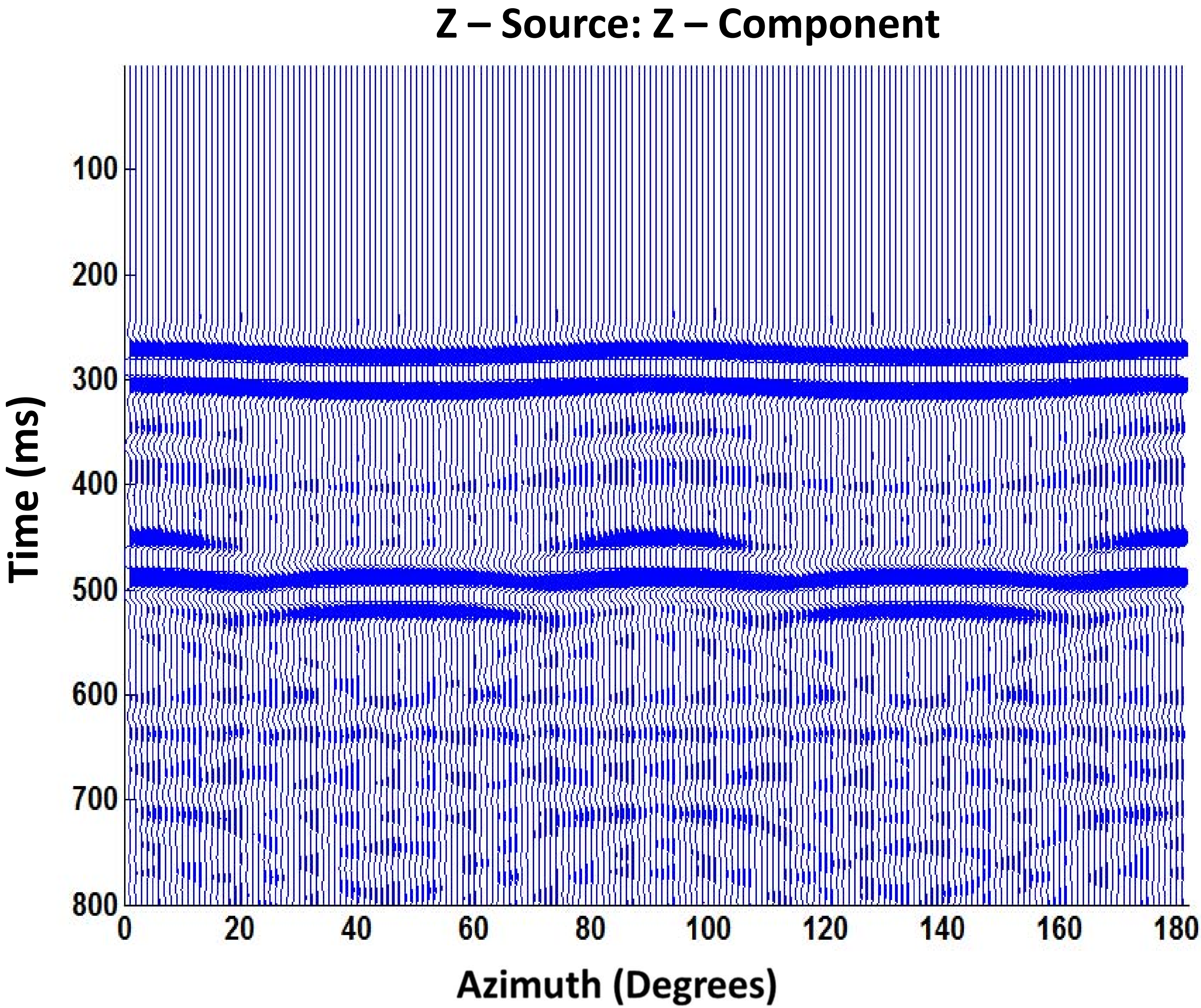
Physical Modelling

Khaled Al-Dulaijan et al (2013 poster) “A physical model investigation of P and S wave azimuthal anisotropy on transmission”



Z – Point Impulse Source

- The source receiver placements approximate that used in the laboratory for *physical* modeling.
- All parameters used in the numerical modeling are also chosen to be as close as possible to those used in obtaining laboratory results.
- *X, Y and Z* point sources each with *X, Y and Z* receiver component arrays are presented.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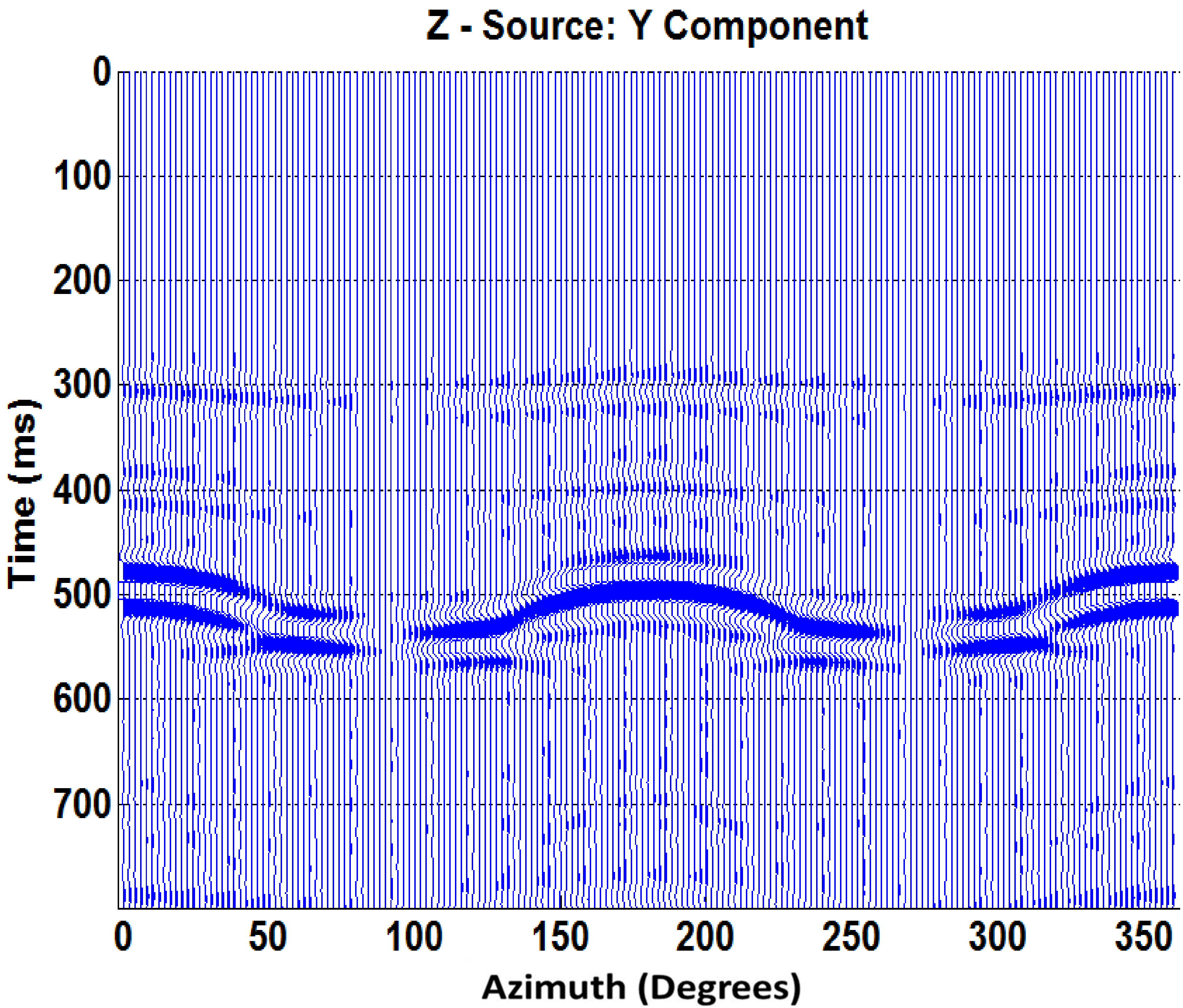

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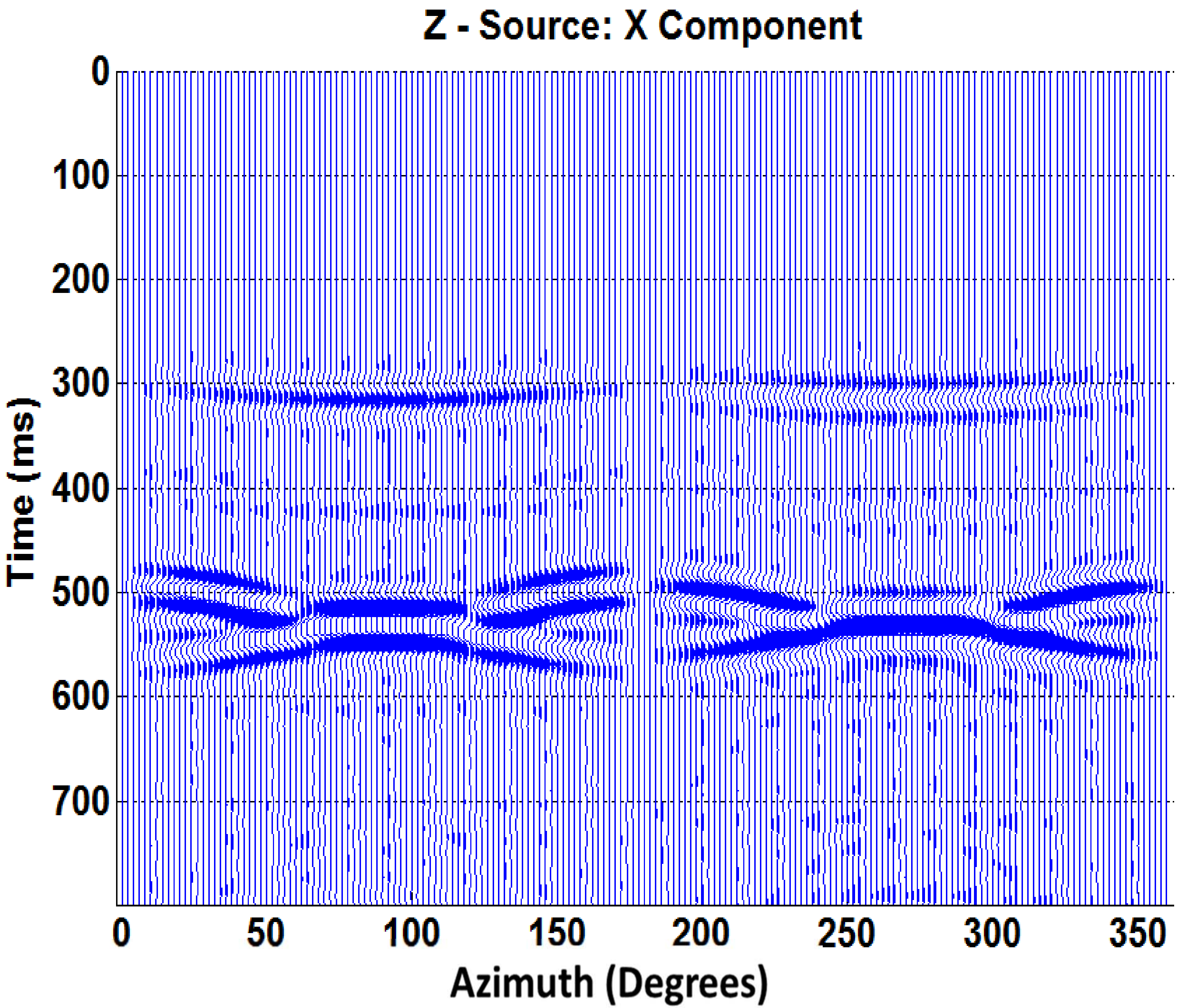
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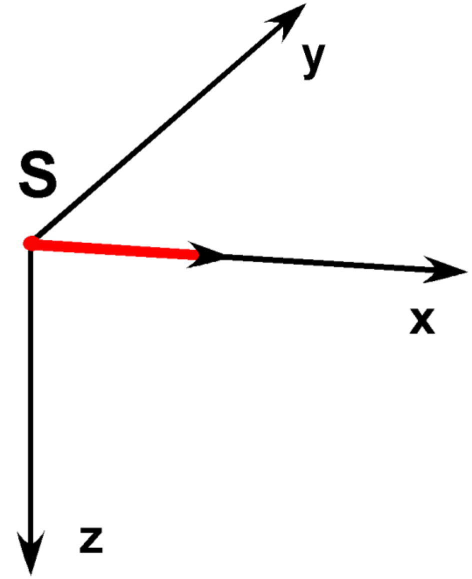
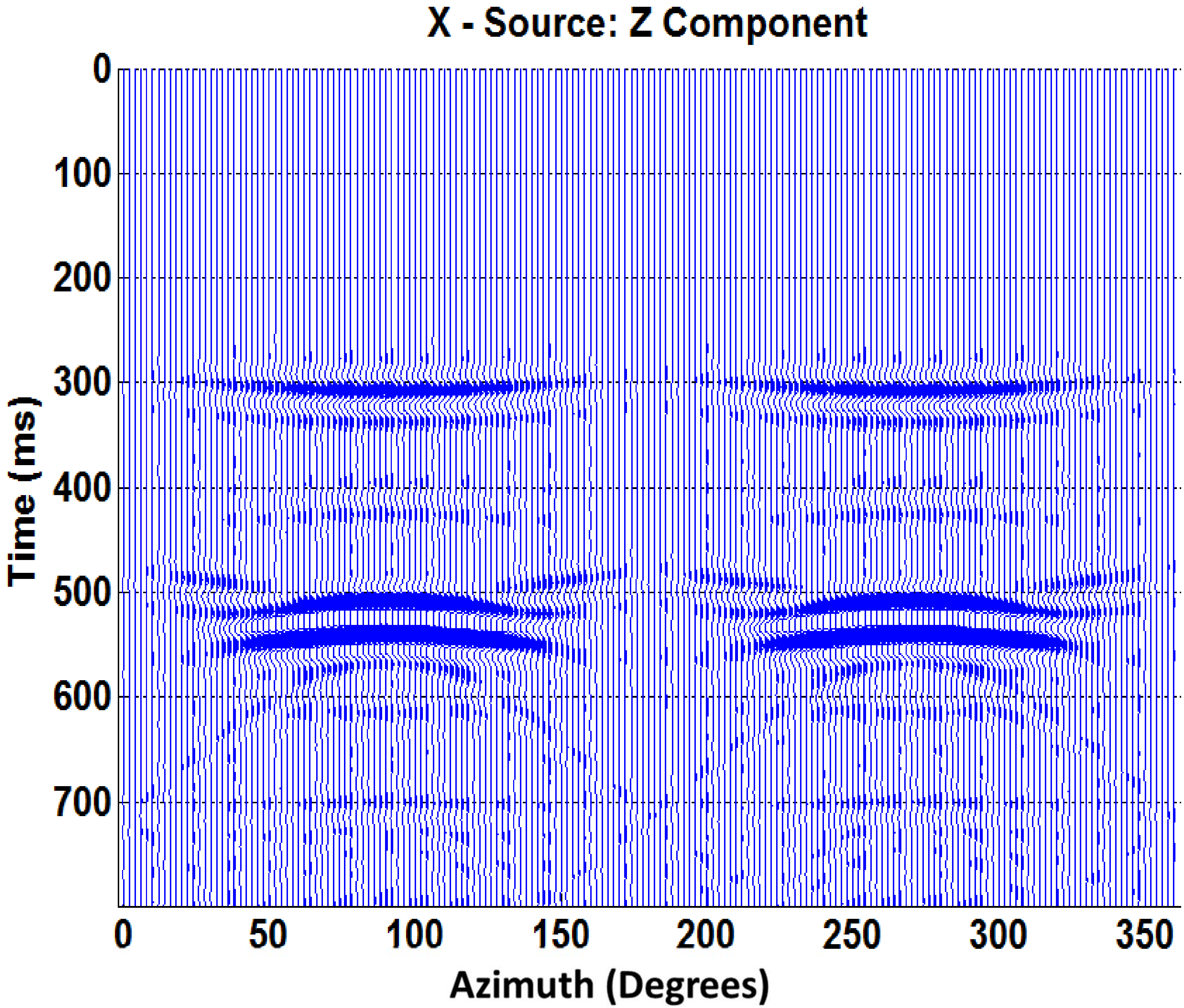
X – Point Impulse Source

- **Point Source in the direction of the positive x – axis.**

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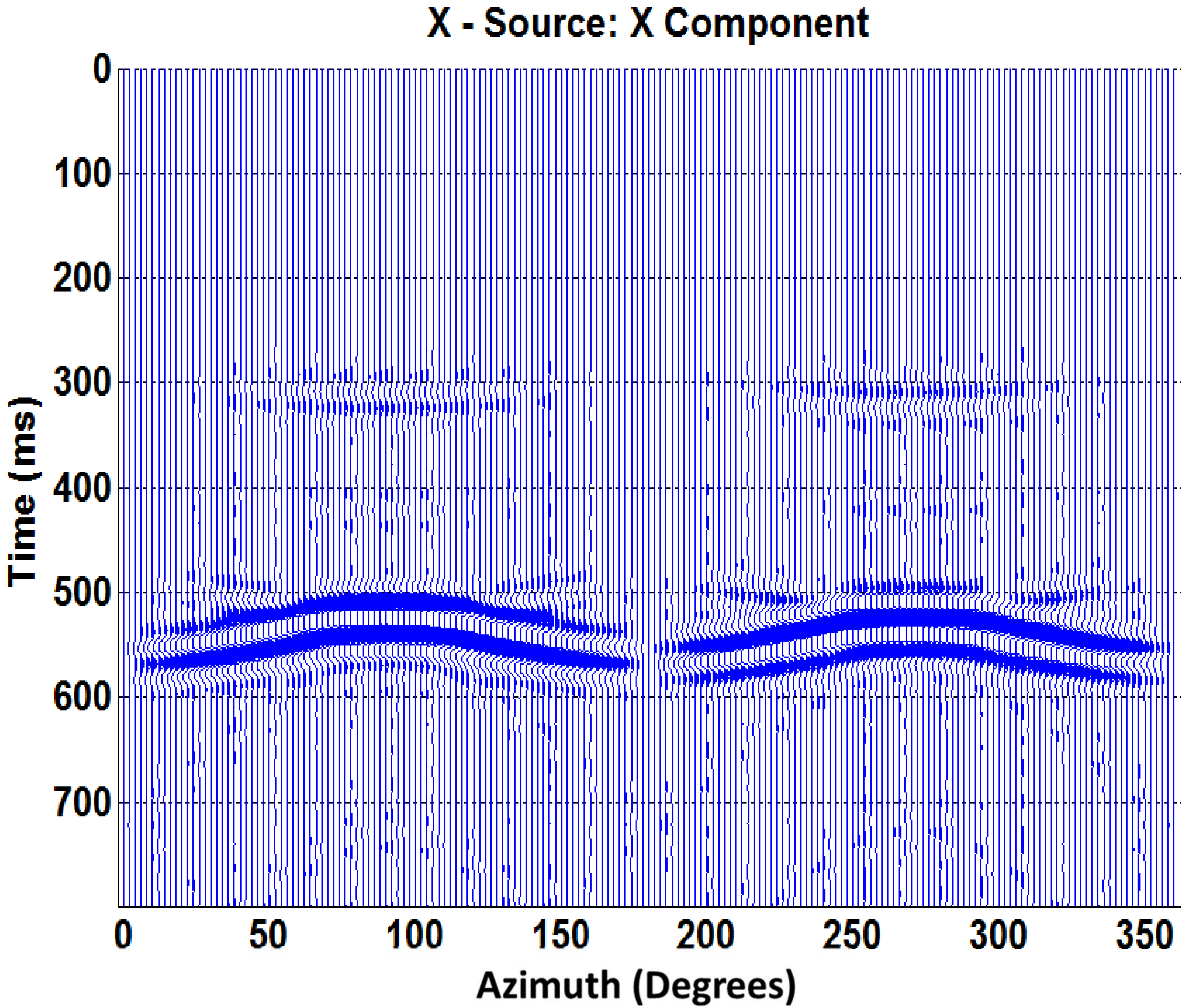
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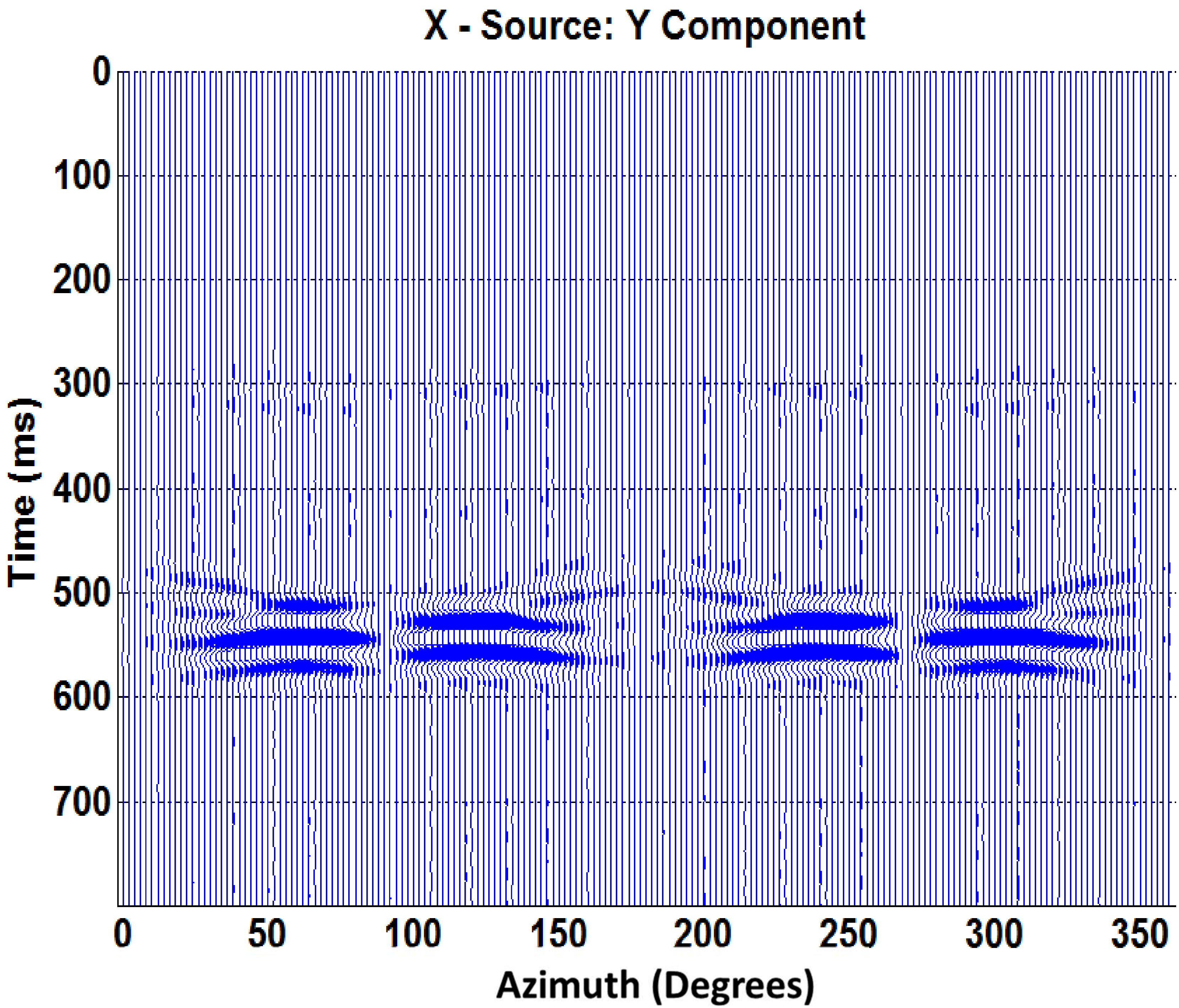
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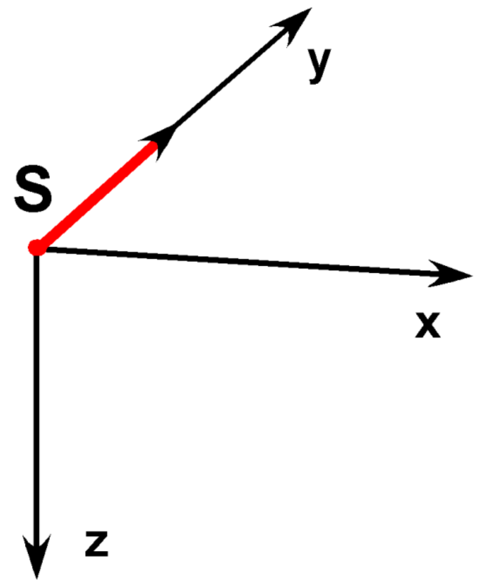
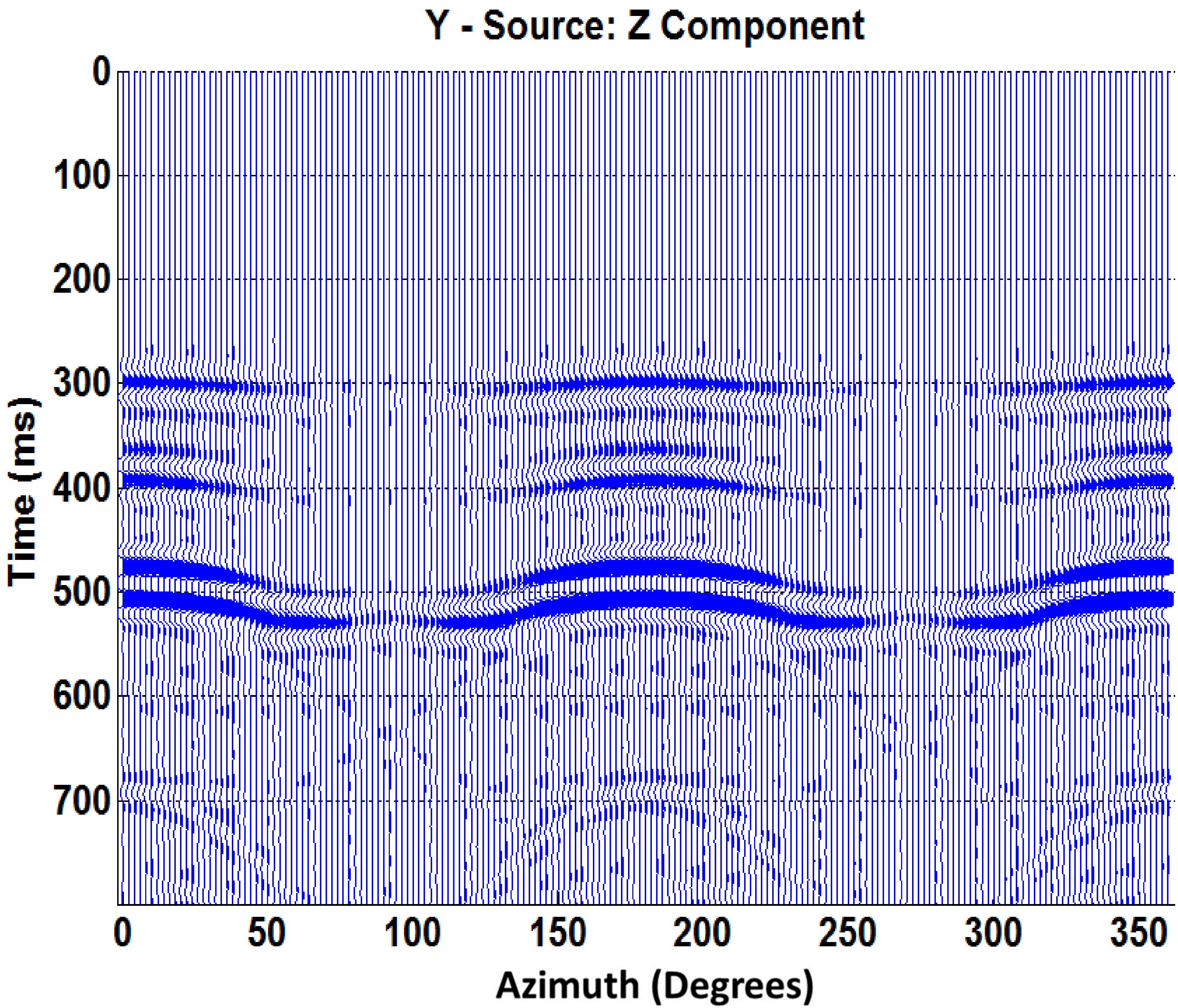
Azimuth (Degrees)

Y – Point Impulse Source

- **Point Source in the direction of the positive y – axis.**

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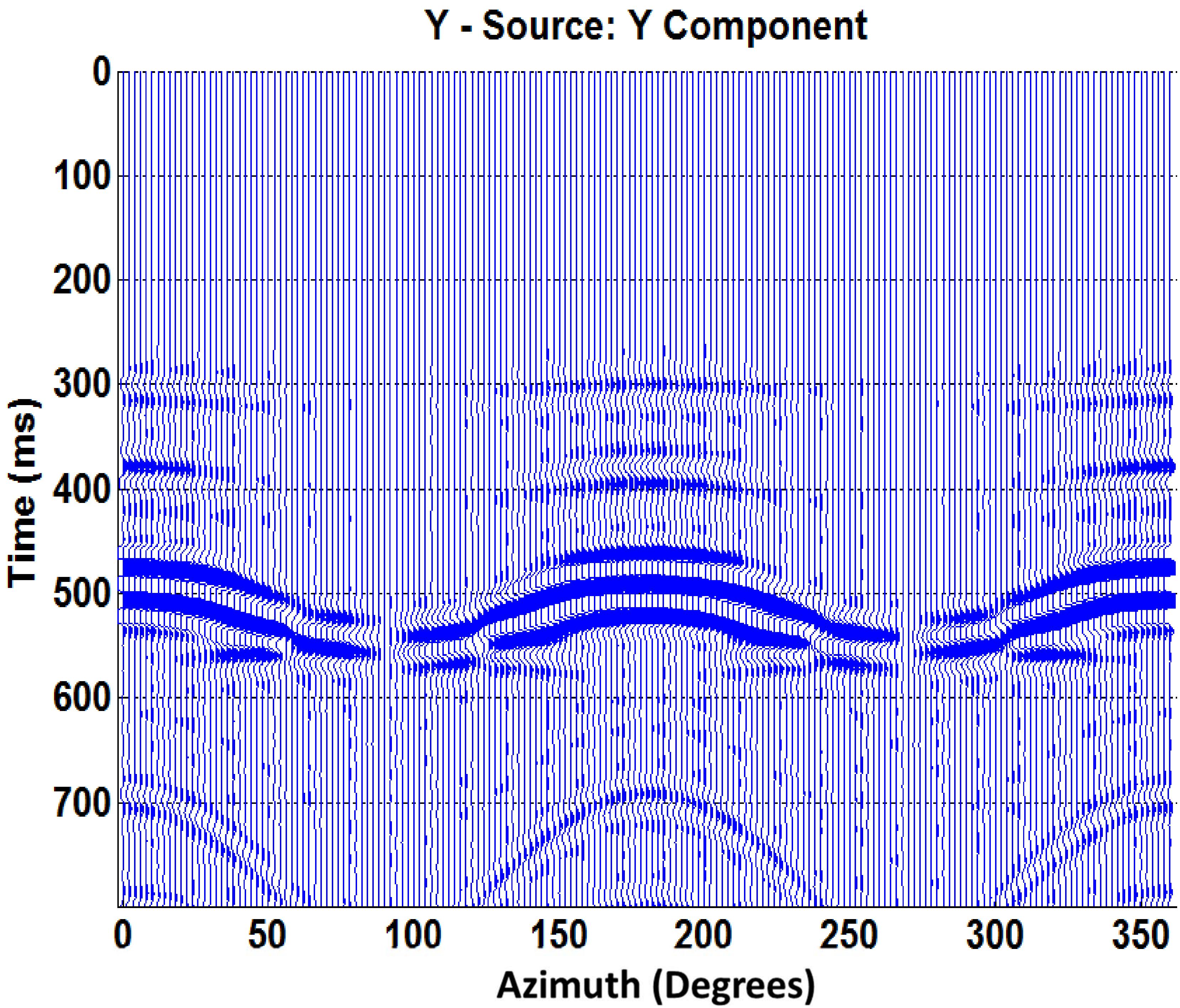

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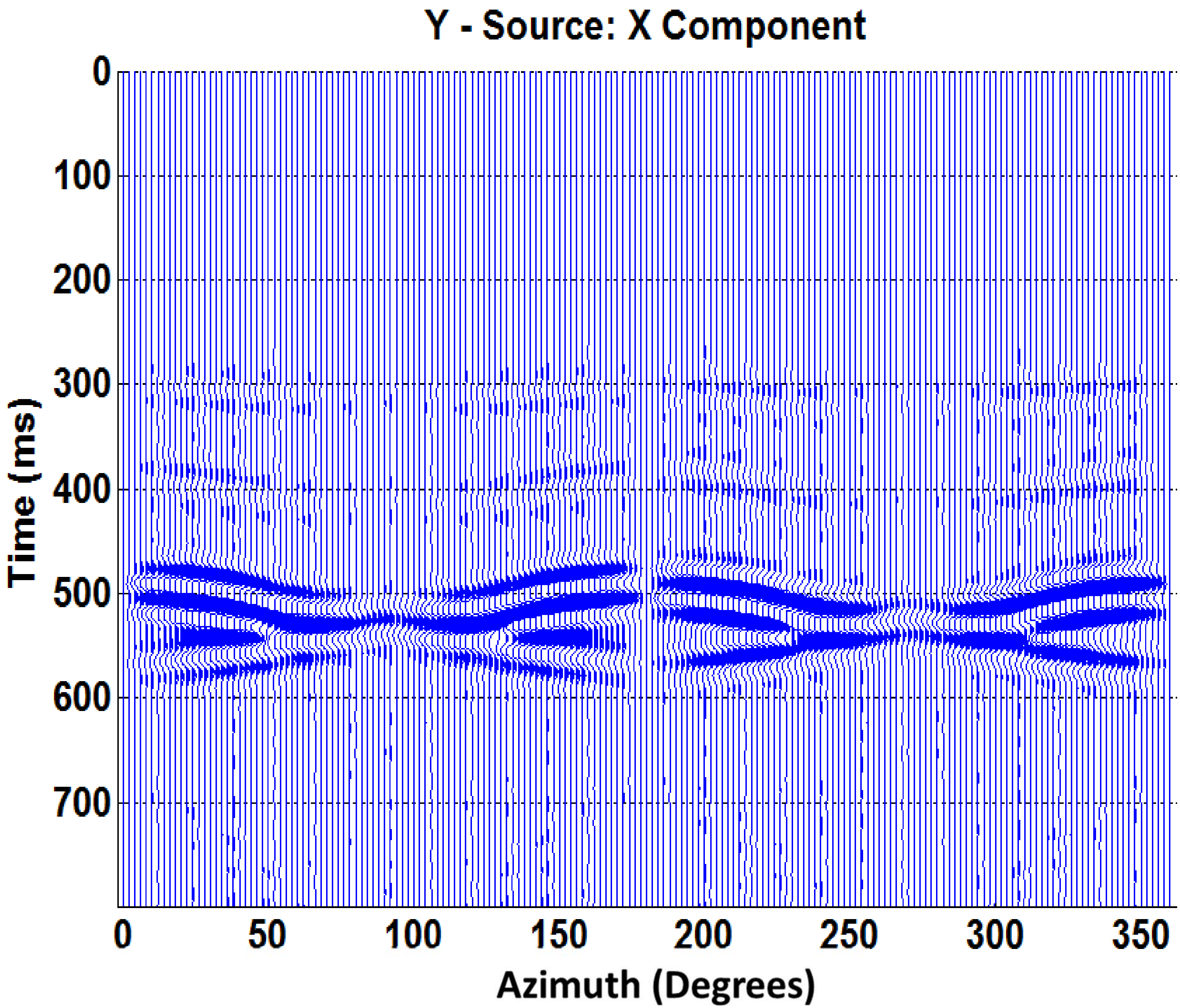

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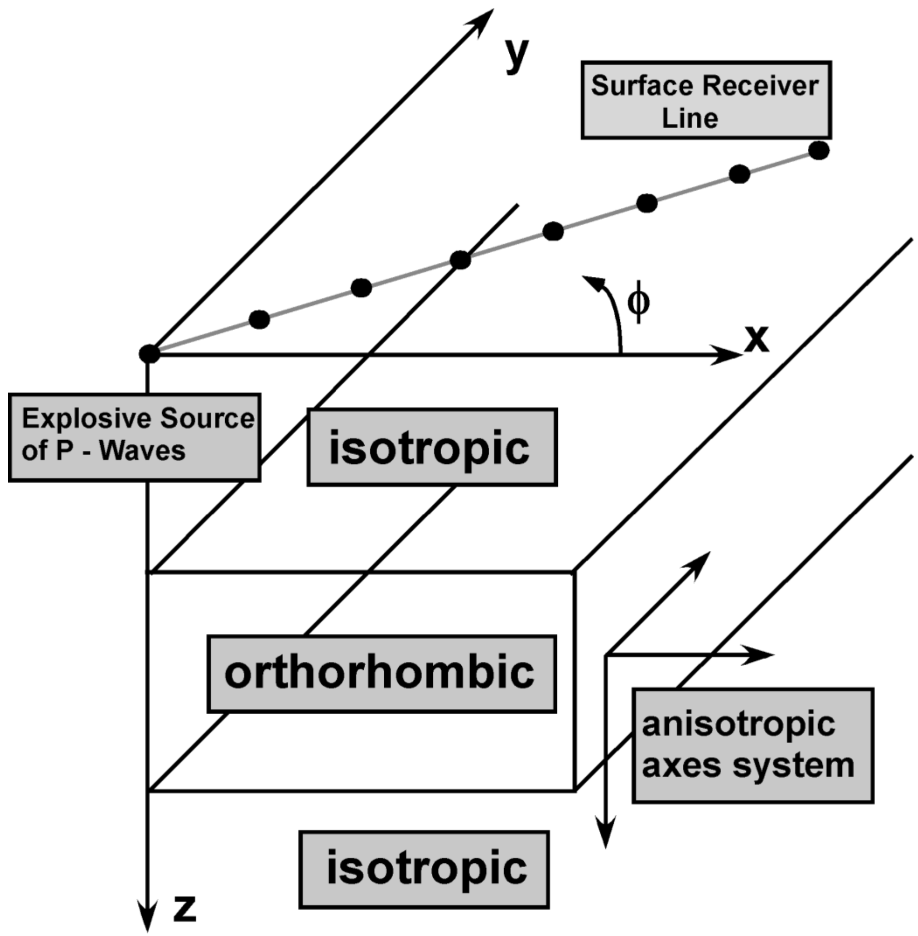
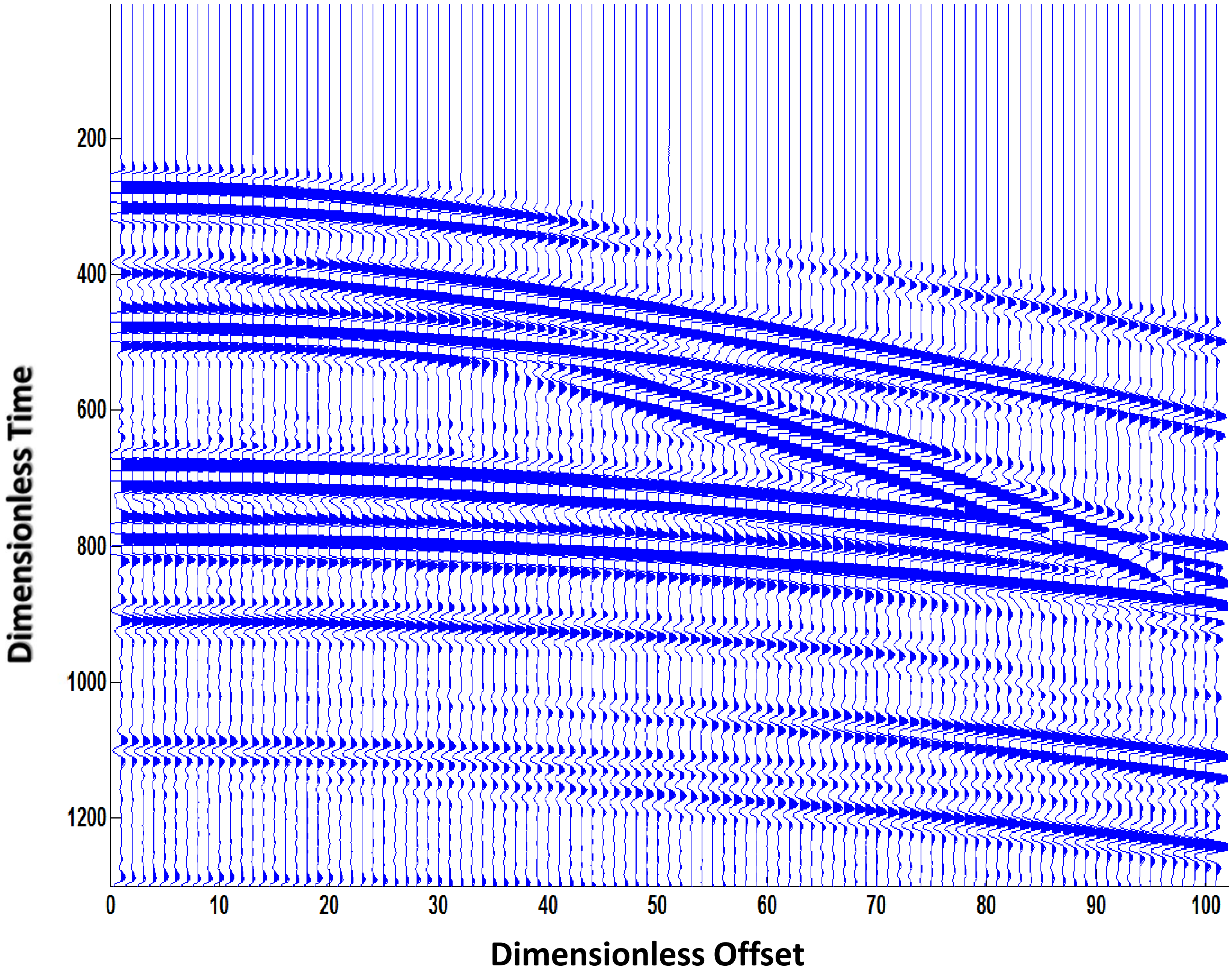
Explosive Source of P – Waves at Free Surface

- **Receivers at Free Surface.**
- **Receiver Line at 30^{o} w.r.t. x – axis in the (x,y) plane.**
- **3 Components of Displacement :**
  - **(1). V – Comp**
  - **(2). Inline – Comp**
  - **(3). Xline – Comp**

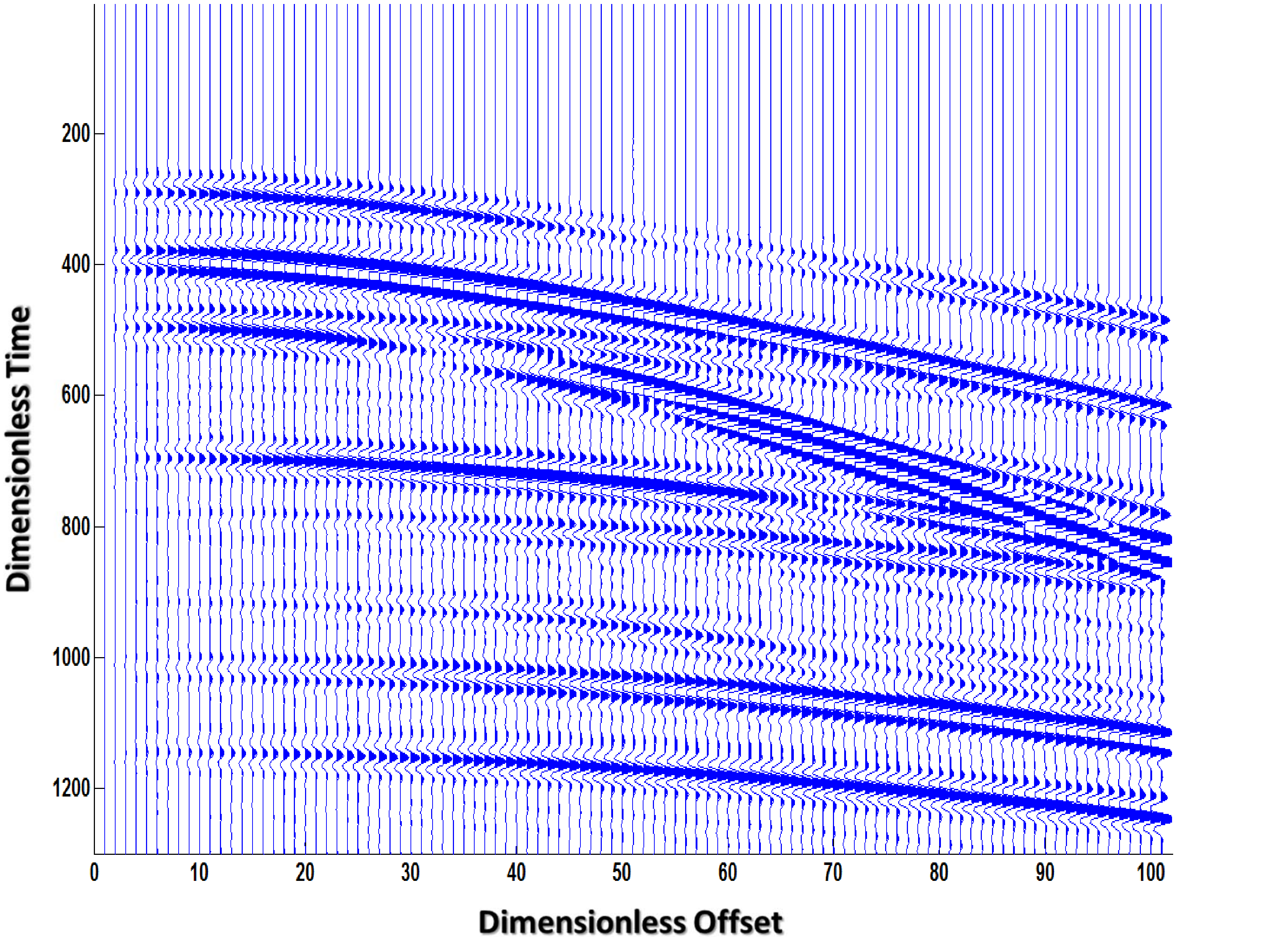
Shooting geometry for offset gather



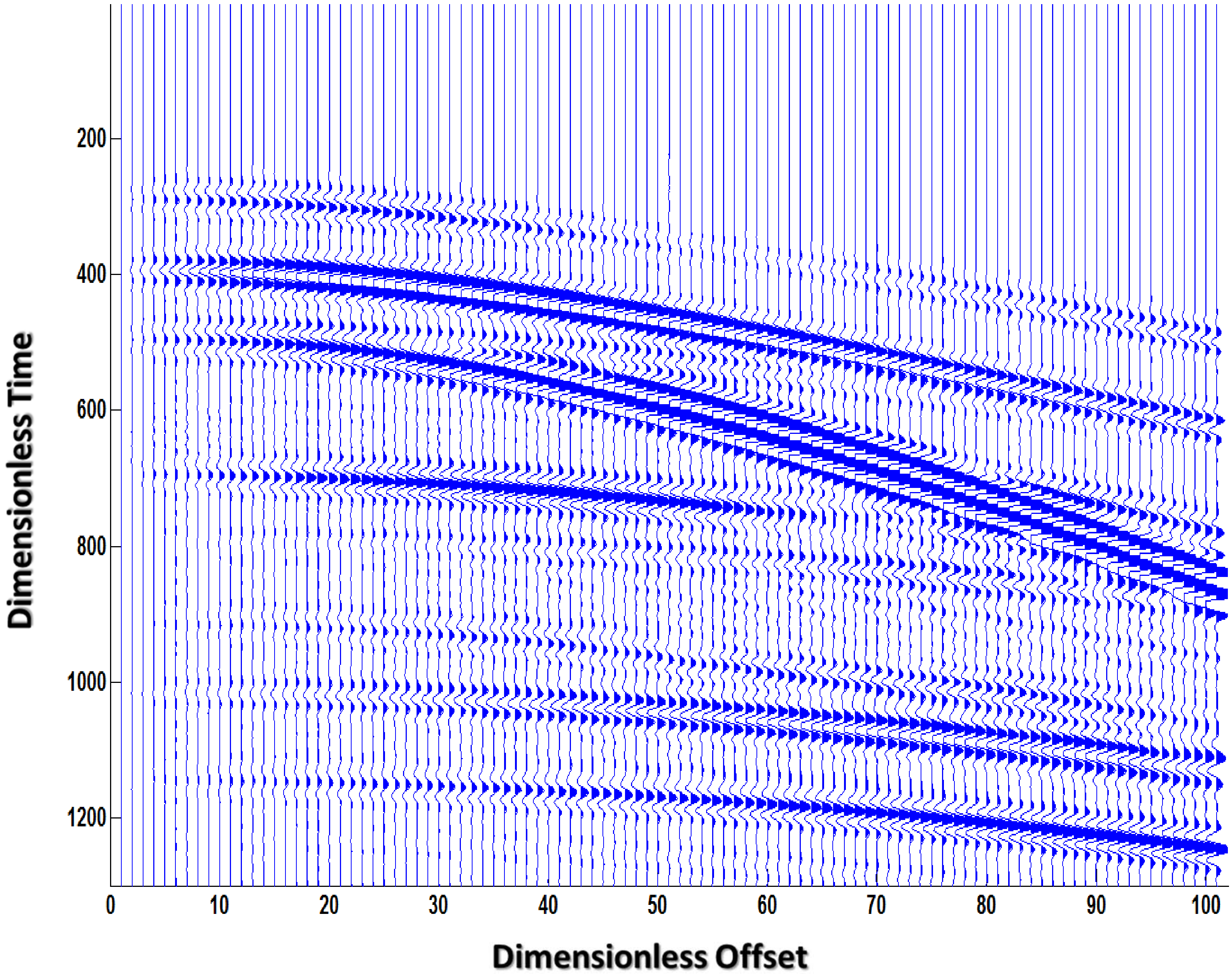
Explosive P Source: V – Comp



Explosive P Source: Inline – Comp



Explosive P Source: Xline – Comp



Conclusions

Reflectivity_fd codes are released ("beta") for acoustic, isotropic elastic, and VTI elastic.

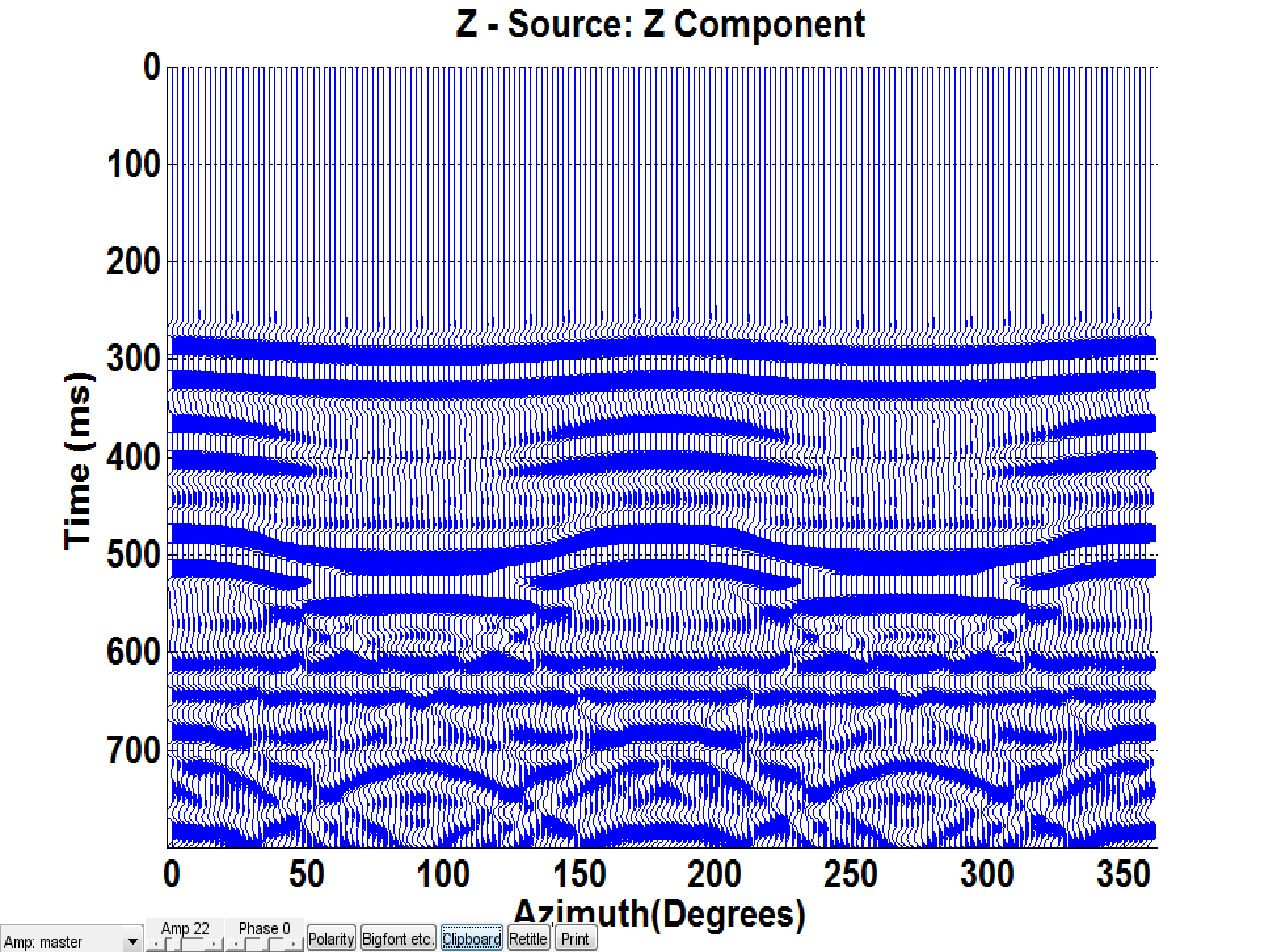
An orthorhombic code is being tested against physical model data. It may be releasable early in 2014. We are interested in producing models for sponsors upon request.

Triclinic appears possible

Acknowledgements

The first author wishes to thank the CREWES Sponsors for their financial support as well as Professors G.F. Margrave and L.R. Lines for additional support from NSERC Operating and Strategic Grants.

EXTRA



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Amp: master
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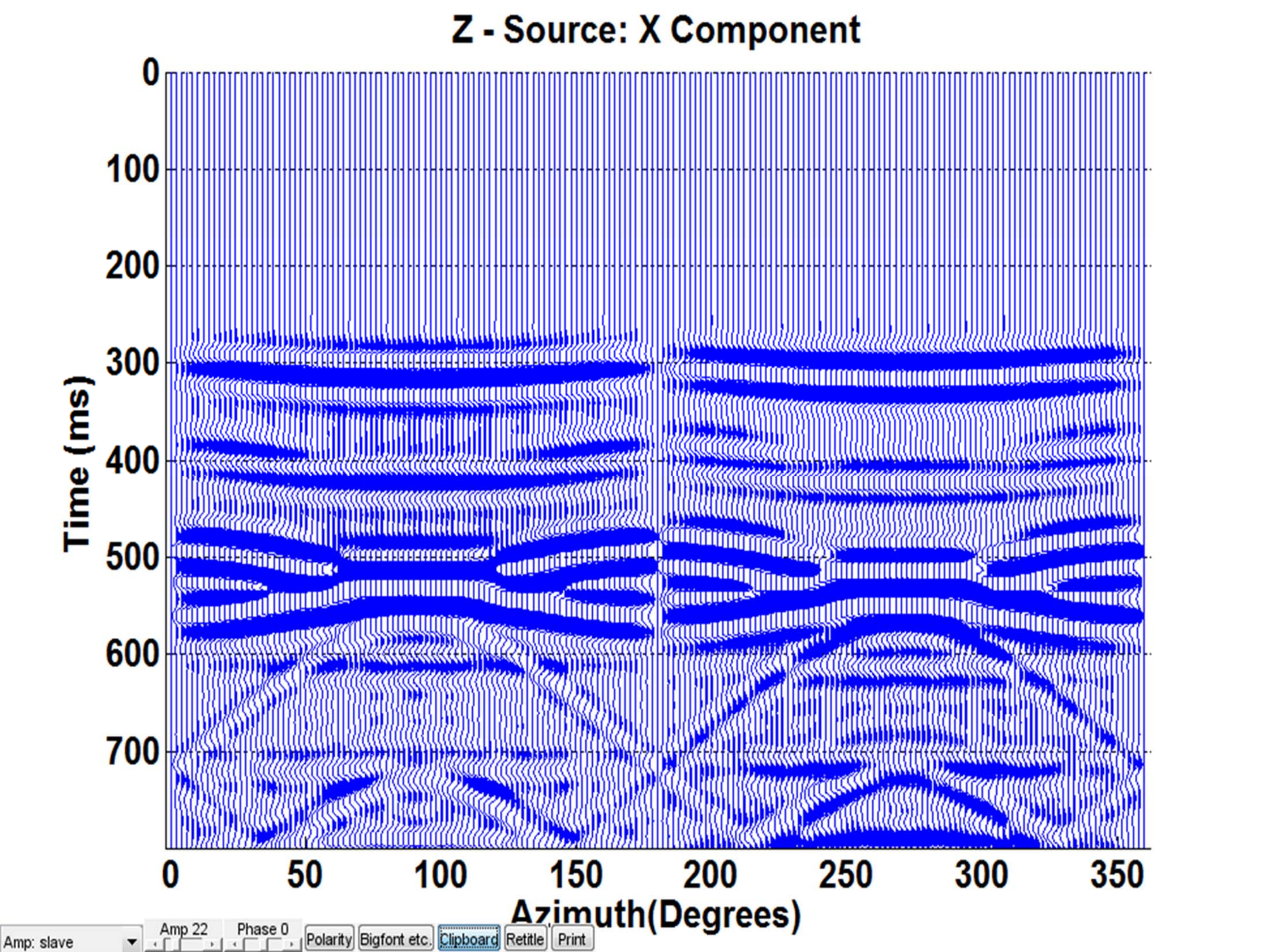
Bigfont etc.
Clipboard
Retitle
Print



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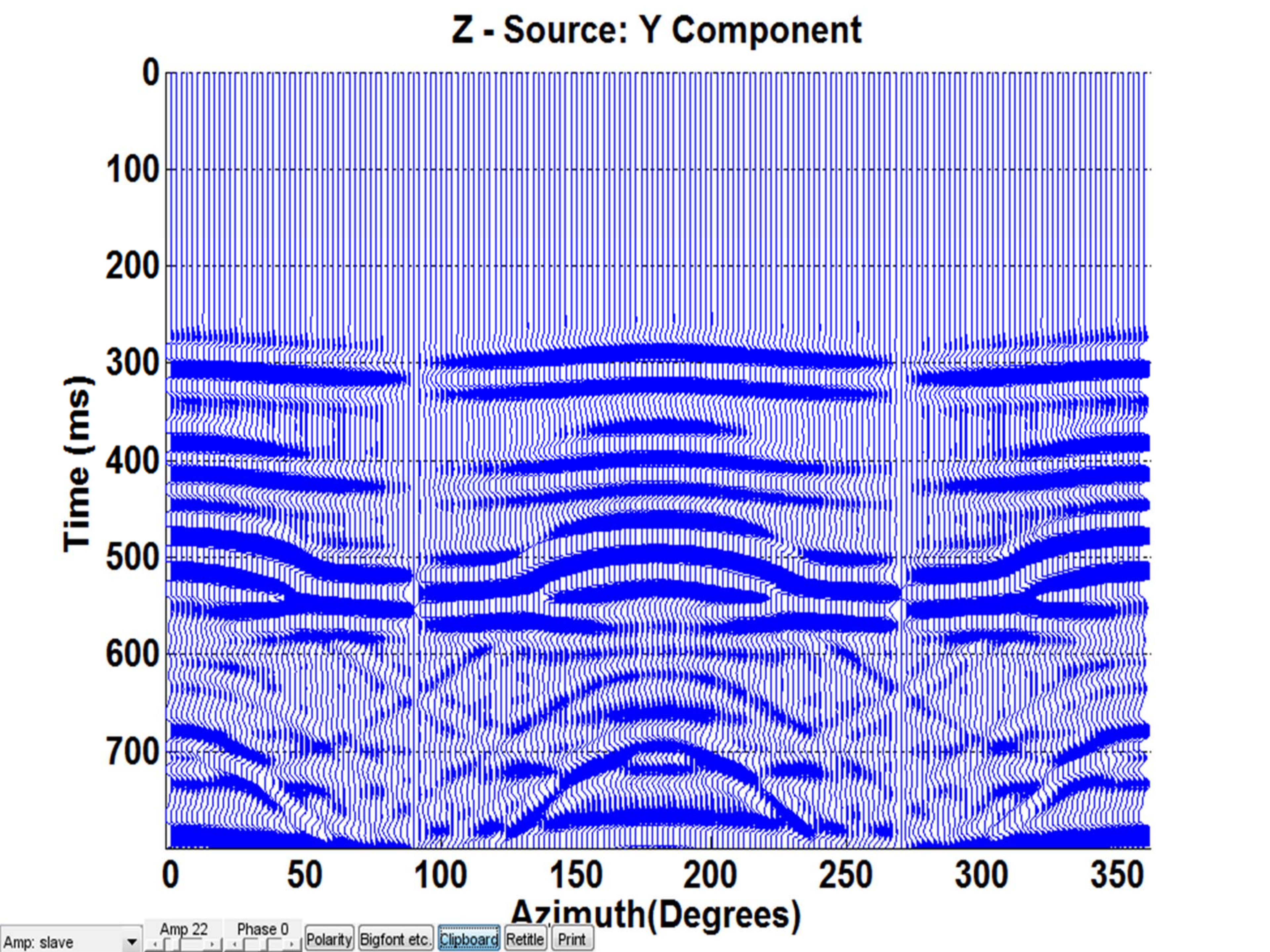
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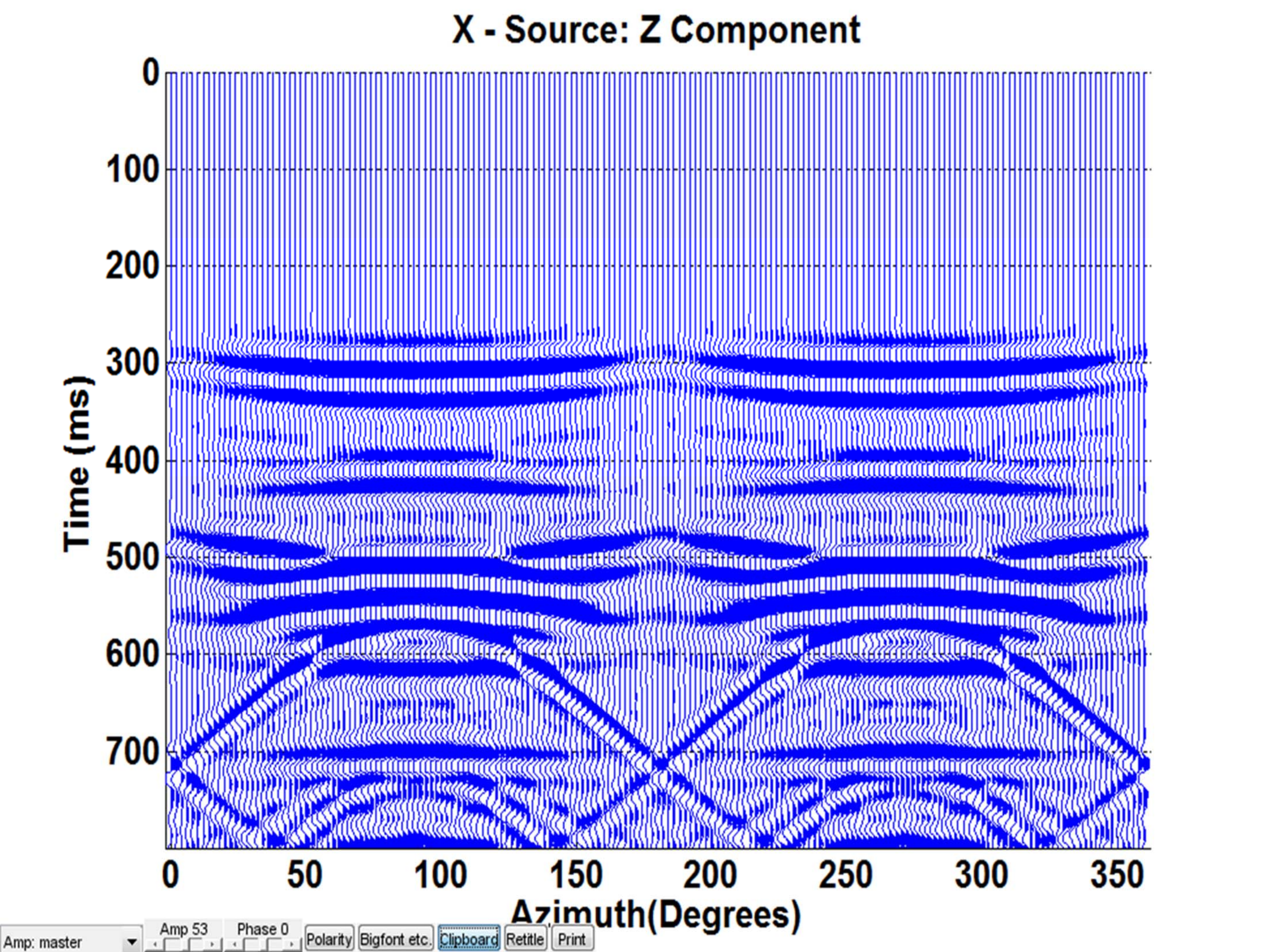
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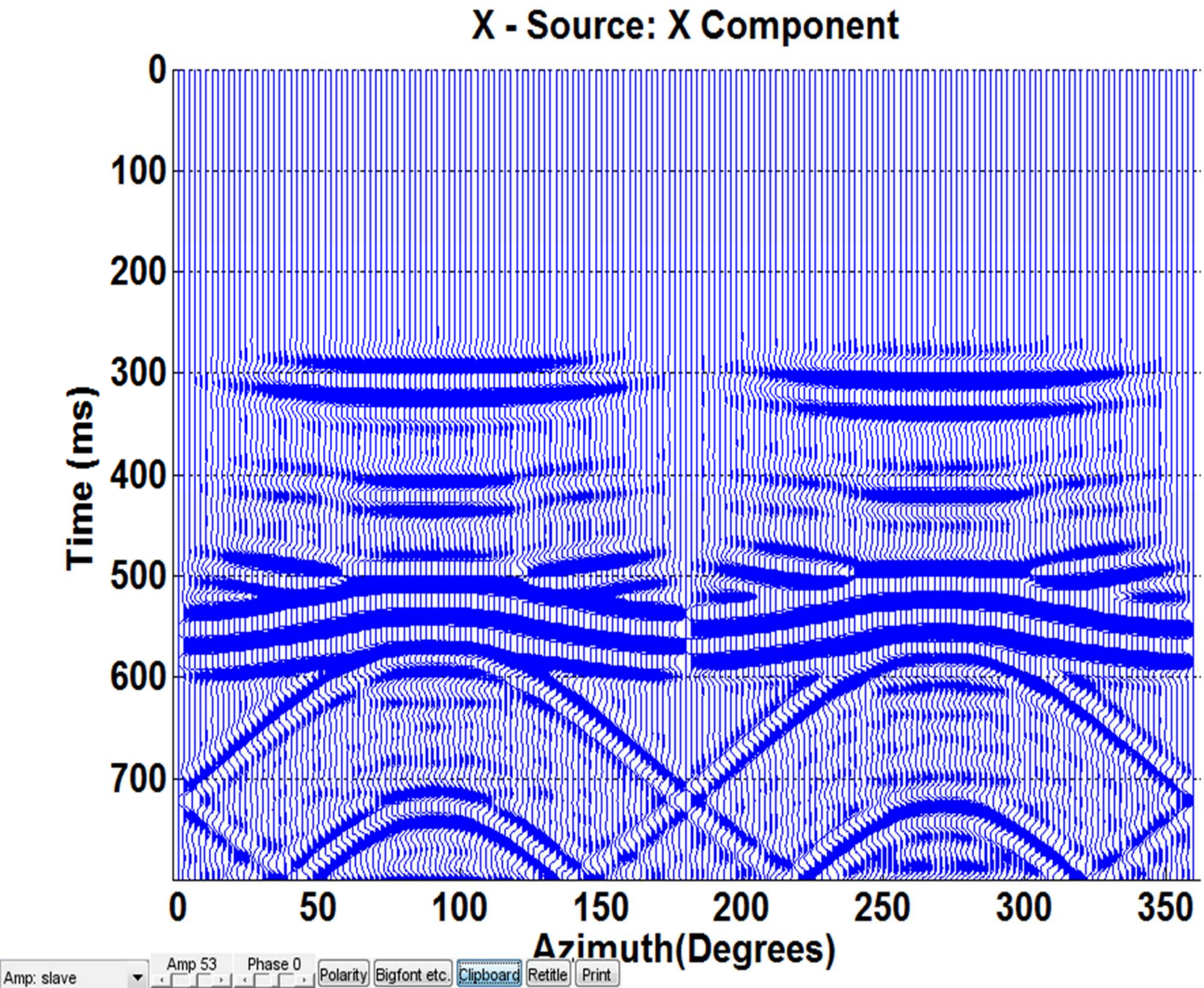

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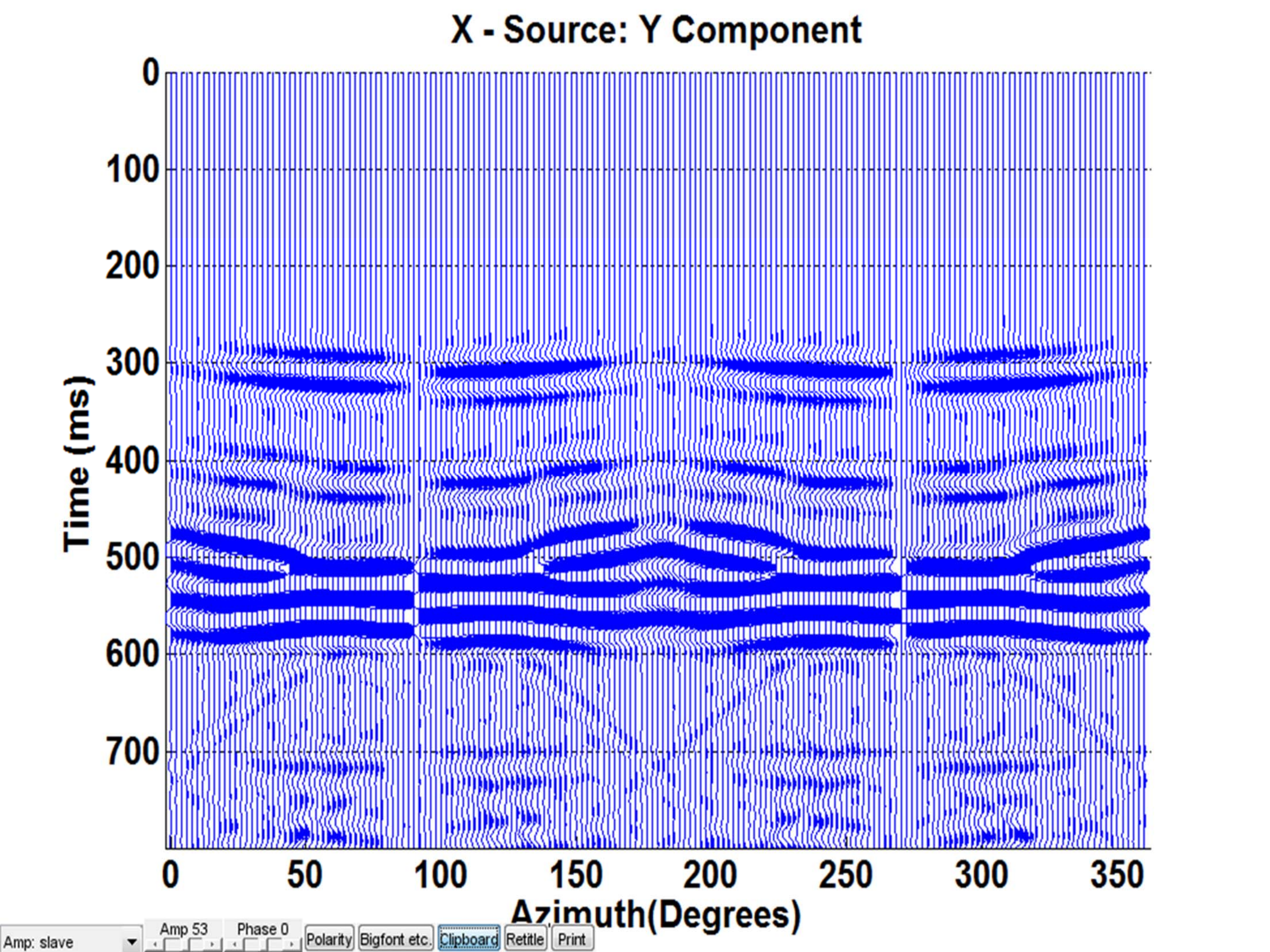

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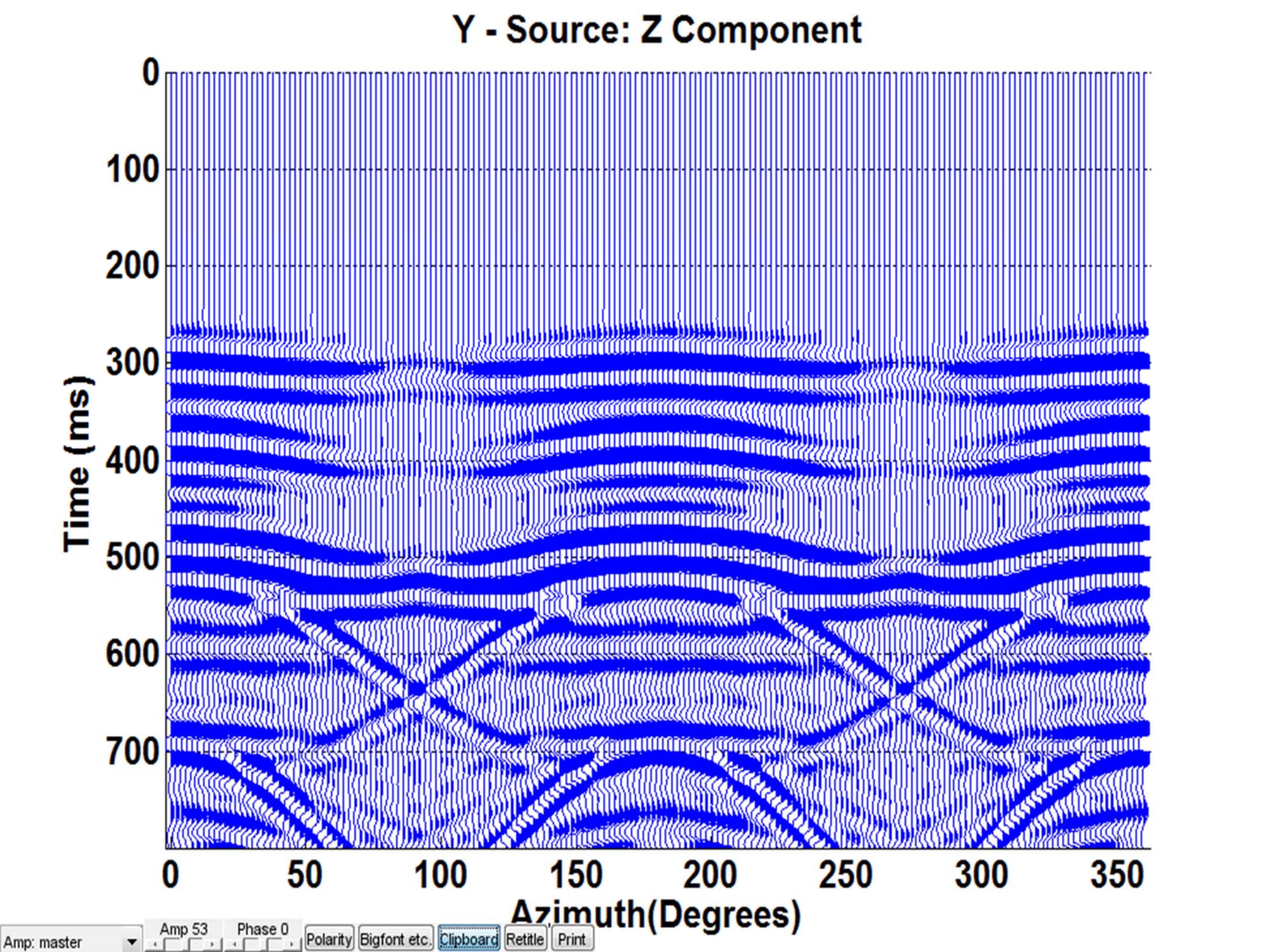

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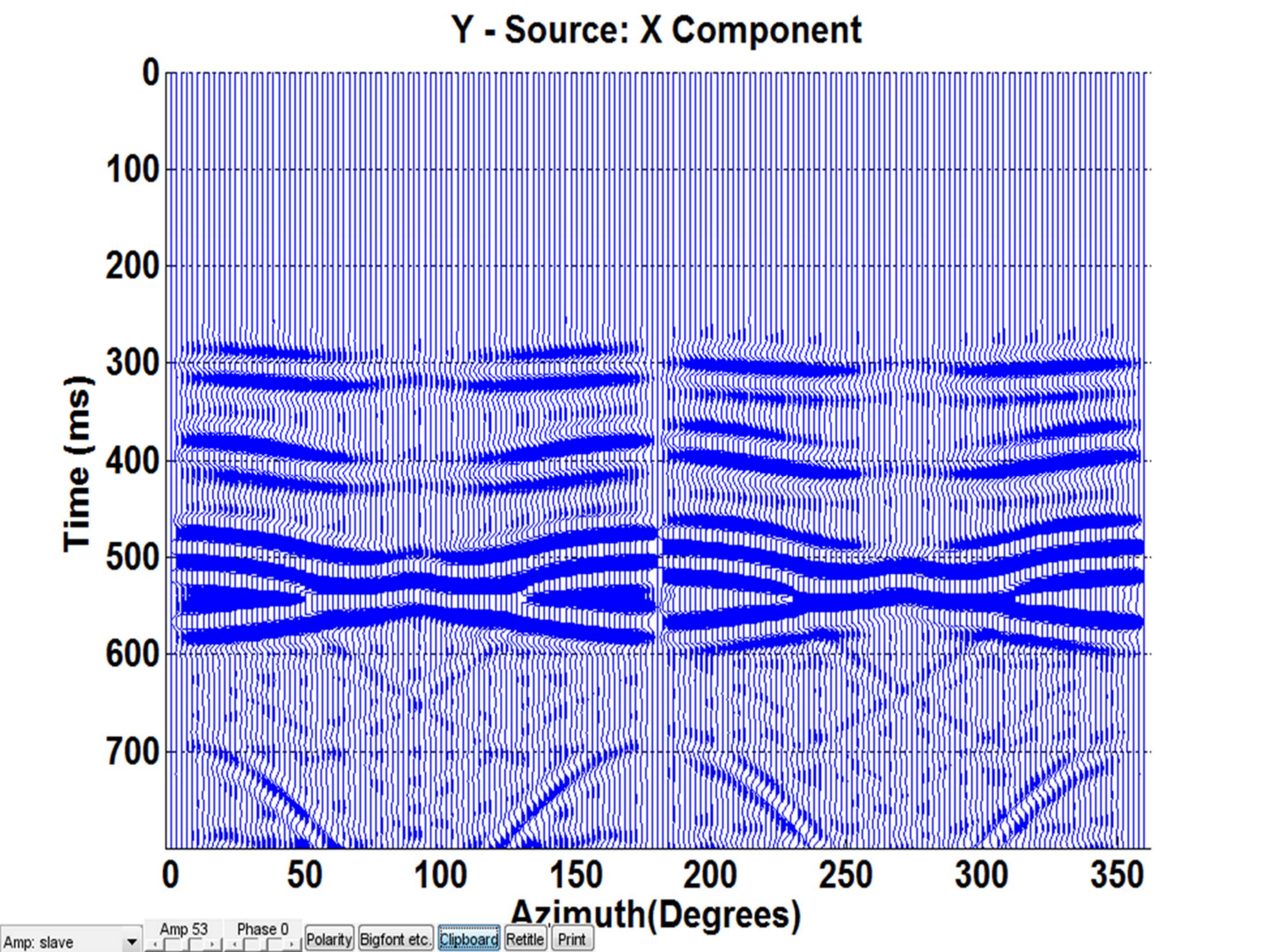
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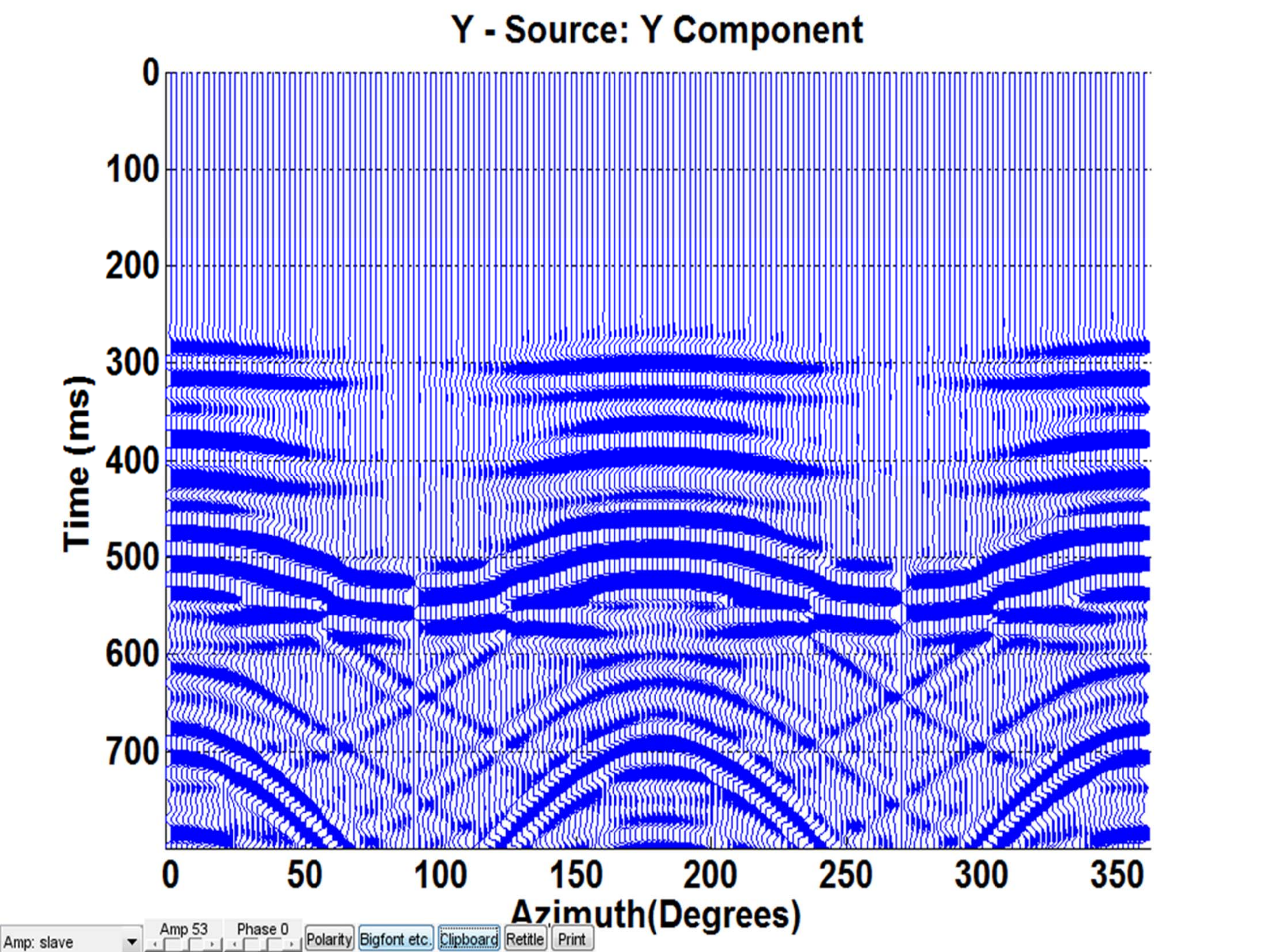

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Reflectivity_FD_*Module* Tools: Previous Work

- **As with the customary reflectivity method, lateral homogeneity is assumed, and these coordinate(s) are removed by transformations.**
- **A problem in depth *(z)* and time *(t)* or frequency *(ω)* remains.**
- **Standard reflectivity methods are constrained by the number of layers in the model. In the FD case, the model may vary arbitrarily with depth, dependent only on the *(z)* grid spacing, Δz.**

- **The choices are:**
    1. **A number of numerical integrations, at enough frequencies to cover the wavelet in the frequency domain, together with the added finite inverse time transform.**
    2. **A finite difference problem in one spatial dimension *(z)* and time *(t)*.**
- **Option 2 has been used for a number of media types and has been shown to perform at least as well as the standard method. It requires one less transform and is much more flexible in specifying parameter variation with depth.**
- **It does involve finite differences and some of the inherent idiosyncrasies. However, as only one spatial dimension is involved, these are minimized.**
- **Acoustic, Elastic and Transversely Isotropic modules have been written for both Offset and VSP recording geometries.**

- **A** beta **release of the preceding software will be made available on the CREWES website.**
- **A updated version of all of this should be ready early in the new year.**